the north, with its highly standardized school system, may have to import its scientific spirit from the corn and canning clubs of the south? If we science teachers wish to avert such a humiliating catastrophe, there is but one thing to do; go to work and develop an equally efficient industrial science in the schools.

This is the only thing that will statisfy the present demand of the public and convert the schools of a machineless age into educational institutions that will turn out pupils competent to understand and to cope with this age of machines. For machines are one of the products of science; and if they have caused misery and slavery among workmen and have reduced human beings to machines, it is because they have been owned and manipulated by men who did not possess the scientific spirit. Machines are bound to master and to control men who try to manage them with words or with the ideals of the past machineless age. Only men with the true scientific spirit are able to understand the real meaning of machines and to use their power for the uplift of humanity. Only men with the sacred faith can ever hope to master and to control them permanently.

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THE FUNCTIONS OF AN ENVIRONMENT[1]

In its nature the present paper falls within the field of abstract physical science, and it can, I fear, interest biologists only through its conclusions. But there is reason to believe that by means of these conclusions a trustworthy foundation for the systematic study of the environment may be established.

The result of my recent inquiry into the relation between the organism and the environment[2] has been, as I believe, proof that a hitherto unrecognized order exists among the properties of the elements. This new order is, so to speak, hidden, when one considers the properties of matter abstractly and statically. It becomes evident only when time is taken into consideration. It has a dynamical significance, and relates to evolution.[3] It is associated with the periodic system of the elements in somewhat the same way that the functional order is related to the structural order in biology. Hence it is not independent of the other order, but may be said to lie masked within it.

This is no novel experience, that the consideration of phenomena in time should lead to new points of view. In truth, it might almost have been said *a priori* that a new order must be revealed by a study of the properties of matter in relation to evolution.

This order may be described abstractly as follows:—The properties of matter are not evenly distributed among the elements, nor in such a manner as can be explained by the laws of chance, nor are they altogether distributed in the manner which the periodic system describes. If the extremes be considered, all the physical and chemical properties are distributed with the very greatest unevenness, so that the extremes are concentrated upon a few elements, notably hydrogen, oxygen and carbon. As a result of this fact there arise certain characteristics of the cosmic process which could not otherwise occur.

The characteristics which make up this unique ensemble include the greater number of characteristics and especially the most important and the most conspicuous physical and chemical properties. This order has for cosmic and organic evolution extremely important results—maximal stability of physico-chemical conditions and maximal complexity in the physico-chemical make-up of the surface of a planet; further, the possibility of maximal complexity, durability and activity of physico-chemical systems in such an environment.

All the considerations upon which these results are based are purely physico-chemical,

[1] Read before the American Society of Naturalists, December 31, 1913.

[2] "The Fitness of the Environment: An Inquiry into the Biological Significance of the Properties of Matter," New York, The Macmillan Company, 1913.

[3] I do not, of course, refer to radioactivity, and the possible evolution of the elements.

and are quite independent of biology in any respect whatsoever. Biology is nevertheless dependent upon them, for life can manifest itself only in active physico-chemical systems. Thus a further and more interesting conclusion arises:—In fundamental characteristics, viz., in the physical and chemical properties of water and carbonic acid and in various other similar respects, the actual environment is the fittest possible abode of life.

To some of my critics this statement not unnaturally seems extravagant.[4] But I hope that this may be due to my failure clearly to explain its meaning and its foundation, rather than to a real fallacy in its development. For in the first place it is to be observed that by fundamental characteristics I mean just those abstract physico-chemical properties like temperature, concentration, stability, chemical activity, etc., which can be measured. And in the second place, I mean not merely a few of such characteristics, but, so far as physical science can recognize them, all such characteristics. Now there can be no doubt that, in respect to these things, water, carbonic acid and the three elements are really unique, and nobody who has examined the evidence has thus far expressed a doubt of it. I need hardly add that I am speaking of the world as we know it and not of any hypothetical world in which matter assumes unknown forms and activities.

The difficulty, then, must lie in what appears to certain biologists, though I think not to the physicists, as an unwarranted assumption. This is that stability, wealth and variety of supply of matter and energy, and mobility thereof, and a host of other similar characteristics, must be an advantage to life in its effort to evolve, and that this is true not merely of life as we know it, but of any possible life manifesting itself in the world as we know it, in this world of our modern astronomy, physics and chemistry. Further, that the greater the magnitude of these characteristics the greater the advantage to life, and hence that, among the compounds and elements which we know, the environment made of water and carbonic acid on a planet's surface is the fittest. Of course I do not mean this planet—this earth—but any planet constituted like those of our universe; for I am dealing abstractly, not specifically, with cosmic evolution.

This difficulty raises the question, which evidently can be but imperfectly answered, what are, speaking generally and abstractly, the relations between any material system and the rest of the world? This, once more, is a purely physico-chemical problem.

As a result of the thermodynamical studies of Willard Gibbs and his development of the phase rule, a large part of modern physical chemistry is concerned with the classification of systems, their activities, and the conditions of equilibrium within them. An aggregate of matter occupying a position of space is a physico-chemical system. In physical chemistry it is customary, for the sake of the simplification, to study closed systems, that is to say, systems which are not exchanging matter or energy with the outside world. But it is quite possible to proceed from these closed systems to such as are exchanging matter and energy with their environment. Now the phase rule has made possible a very complete and exhaustive classification and description of systems in a perfectly abstract way.[5] Necessarily, therefore, it has provided a complete qualitative physical and chemical analysis of the fundamental characteristics of any system.

In addition to its material and spatial characteristics a system must manifest activity. In the very simplest case it will at least exhibit that motion which we call heat. But activity also has been brought completely under the sway of physical science, for energetics deals exhaustively with all forms of physical and chemical activity.

[4] R. S. Lillie, SCIENCE, N. S., XXXVIII., 337, September 5, 1913; J. Arthur Thomson, *Hibbert Journal*, p. 220, October, 1913.

[5] It must be pointed out that there is a certain incompleteness, which happily is of minor importance for our present purpose, in the failure to take account of such a thing as electrical potential.

It seems to be true (one may note in passing) that with the progress of science the term mechanism has come to mean merely any active system. In what follows I shall, therefore, use the word mechanism in this sense. According to this definition the mechanistic explanation of a phenomenon is simply its explanation as the activity of a system, and this is the only explanation known to physical science.

Finally, in addition to its material, spatial, and energetic characteristics a system must also be characterized as a whole and in its parts, in its form, structure, and activity by durability. The consideration as well of time as of activity permits the transition from the statical to the dynamical.

In short, form and size, physical and chemical constitution, activity and duration are the general factors to be considered in any phenomenon whatsoever. In the complete description of any mechanism all must be considered, but, for the purposes of physical science no others need be, or indeed can be, introduced.

It is accordingly possible, without any examination of the results of biology, and even in complete ignorance thereof, to investigate the fitness of the special properties of matter for any mechanism, *i. e.*, for mechanism in general.

THE SYSTEM

The fundamental characteristics of a system are the components, the phases, the concentrations, and further temperature and pressure. Hence fitness for *any* system involves the possibility of the greatest number and variety of components and phases, of the widest ranges of concentrations, temperatures and pressures. It has been shown in "The Fitness of the Environment" that the number of possible components (chemical compounds) consisting of carbon, hydrogen and oxygen is far greater than in the case of other elements; that the meteorological cycle mobilizes on land and sea far greater numbers of other elements than would be the case if water were not the active agent in the process; that an aqueous solution is capable of holding a far greater number of components in far greater concentrations than can any other; that water makes possible, through its unique thermal properties and its unique qualifications in relation to colloids, the greatest possible number and variety of phases. Moreover, many other similar facts have been established without coming upon an unfavorable instance or exception in the course of prolonged search. As for wide ranges of temperature and pressure, they may be passed by, for as a rule such conditions are not consistent with durability, hence their importance is very restricted.

ACTIVITY

Any activity is possible provided a suitable system exists and provided suitable energy is present. This fact leads us back to the conclusion that chemical transformations of hydrogen, oxygen and carbon are the very best chemical means of storing and liberating energy, and that the reactions of organic compounds permit the most delicate adjustments of such transformations. Further it has been shown that the unique thermal properties of water are most highly suited to the storing and distribution of energy, while its solvent power facilitates osmotic pressure and diffusion. It may also be mentioned as a final instance of fitness for activity, among many other examples, that the electro-chemical characteristics of water are in many ways the best possible sources of electrical activity.

DURABILITY

Durability depends upon stability of conditions and upon supplies of matter and energy to replace what is used up.

The stability of physico-chemical conditions, which is due to the presence of water and carbonic acid as primary constituents of the environment, is very great indeed, and, beyond doubt, far greater than what could exist if these substances were replaced by any others. A very large part of all the data of oceanography and meteorology do but illustrate the almost inconceivable efficiency with which water, in the main through its unique thermal properties, completely checks very wide ranges of temperature, and as a rule restricts the

range of temperature within narrow limits in the waters and throughout the earth. Even more exact is the regulation of the alkalinity of the ocean by means of carbonic acid, through its unique solubility and ionizing power. These are but two among many examples of maximal efficiency in regulation.

The renewal of matter and energy are not less highly favored. The properties of water ensure everywhere the highest availability of supplies in the greatest number and concentration. Further the three elements carry with them the possibility of maximal energy supplies. In some respects, indeed, the ubiquity and mobility of water and carbonic acid, their presence in the sea, in the lakes and streams, in the air, and in the soil, which depend upon the combined action of the unique solubility of carbonic acid, the unique vapor tension of water, and its unique surface tension, seem the most remarkable of all fitnesses.

I can not further develop these considerations here, for they are too numerous and too varied, but I have elsewhere treated them extensively.[8] In truth, all the properties of water, of carbonic acid, of the compounds of carbon, hydrogen and oxygen, of the ocean, and of the meteorological process, so far as the present state of science permits their analysis, need to be considered, for each adds to the argument. Each contributes to duration, or to activity, or to the phases, or compounds, or concentrations of possible systems. Each tends to increase rather than to restrict the possibilities of mechanism, and each is the best, or nearly the best, among all the known substances in the world. And the ensemble of these properties is perfectly and extraordinarily unique.

All of these relationships are merely physical, nothing about them is biological except their importance.

From such considerations there can be but one conclusion: the unique ensemble of properties of water, carbonic acid and the three elements constitutes among the properties of matter the fittest ensemble of characteristics for durable mechanism. No other environment, that is to say no environment other than the surface of a planet upon which water and carbonic acid are the primary constituents, could so highly favor the widest range of durability and activity in the widest range of material systems—in systems varying with respect to phases, to components, and to concentrations. This environment is indeed the *fittest*. It has a claim to the use of the superlative based upon quantitative measurement and exhaustive treatment, which is altogether lacking in the case of the fitness of the organism. For the organism, so we fondly hope, is ever becoming more fit. and the law of evolution is the survival of the fitter.

Yet it is only for mechanism in general, and not for any special form of mechanism, whether life as we know it, or a steam engine, that this environment is fittest. The ocean, for example, fits mechanism in general; also, if you will, it fits the whale and the plankton diatom, but not man or a butterfly. But, of course, as everybody has known since 1859, it is really the whale and the diatom which fit the ocean. And this leads to the true conclusion of our investigation.

Just because life must manifest itself in and through mechanism, just because, being in this world, it must inhabit a more or less durable, more or less active physico-chemical system of more or less complexity in its phases, components and concentrations, it is conditioned. The inorganic, such as it is, imposes certain conditions upon the organic. Accordingly, our conclusion is this: *The special characteristics of the inorganic are the fittest for those general characteristics of the organic which the general characteristics of the inorganic impose upon the organic.* This is the one side of reciprocal biological fitness. The other side may be similarly stated: Through adaptation the special characteristics of the organic come to fit the special characteristics of a particular environment, to fit, not any planet, but a little corner of the earth.

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[8] See "The Fitness of the Environment."

THE PITTSBURGH EXPERIMENT STATION OF THE BUREAU OF MINES

PLANS for the proposed $500,000 experiment station of the United States Bureau of